

## INCHEON BRIDGE: FACTS AND THE STATE OF THE ART



**Sung-Min Cho, Ph.D.**  
TA Team Leader  
Incheon Bridge Construction  
Office, Korea Expressway  
Corporation  
chosmin@ex.co.kr



**Sang-Sup Ahn, Ph.D.**  
Research Director  
Incheon Bridge Construction  
Office, Korea Expressway  
Corporation  
ahnss@ex.co.kr



**Young-Ku Lee**  
Team Leader  
Incheon Bridge Construction  
Office, Korea Expressway  
Corporation  
yglee@ex.co.kr



**Seung-Tak Oh**  
Head  
Incheon Bridge Construction  
Office, Korea Expressway  
Corporation  
ost8282@ex.co.kr

**Abstract:** *Incheon Bridge, 18.4 km long sea-crossing bridge, will be opened to the traffic in October 2009 and this will be the new landmark of the gearing up north-east Asia as well as the largest & longest bridge in Korea. Incheon Bridge is constituted of several special featured bridges including a magnificent cable-stayed bridge which has a main span of 800 m to cross the main navigation channel of the Incheon Port. Incheon Bridge is the first trial to apply AASHTO LRFD (load & resistance factor design) to both the superstructures and the substructures in Korea. Various experiences of advanced design and construction method from the Incheon Bridge project have been propagated by relevant engineers and it is strongly expected that significant achievements in bridge engineering through this project will contribute to the national development of the long-span bridge technologies remarkably.*

**Keywords:** Incheon Bridge, long-span bridge, LRFD

### 1. INTRODUCTION

The mission of Incheon Bridge project is to make 21.4 km long national expressway between Incheon International Airport (IIA) and New Songdo City crossing the Yellow Sea (Figure 1). The 12.34 km length of sea-crossing section of this expressway is being built funded by the private concessionaire and the rest of that has been constructed with the government budget. The expressway has 6 lanes for two way traffics and 86 % of the total length, as same as 18,348 m (approximately 18.4 km) is a continuously connected bridge. This is the Incheon Bridge, which connects the world-famous IIA with main expressway networks around the Seoul metropolitan area through the newly developing Songdo city as Incheon Free Economic Zone.

18.4 km long Incheon Bridge, Korea's longest and largest bridge candidate consists of several special featured bridges including the marine cable-stayed bridge whose main span measures 800 m to cross the vessel navigation channel in and out of the Incheon Port (Figure 2). Constructions were commenced in July 2005 and it is scheduled to be completed by October 2009. 52 months of construction period for this very long sea-crossing bridge might be amazing especially for bridge engineers. Total cost of the project is estimated at 2.5 trillion KRW.

The competent authority of the Incheon Bridge project is Korea Expressway Corporation (KEC), a government corporation in charge of planning, construction, and management of national expressways

under the commission of the Ministry of Land, Transport, and Maritime affairs (MLTM). Special purpose company (SPC) for private investment section is Incheon Bridge Co. Ltd. (IBC), a joint venture between UK based AMEC company, City of Incheon, and other financial firms. SAMSUNG JV, a joint venture of 7 domestic builders including SAMSUNG C&T Corporation is the main contractor for the private investment section and there are also 5 leading builders including HYUNDAI E&C Co. and DAELIM Industrial Co. for the construction of the government financed section.



Figure 1: Locale of the Incheon Bridge

Thanks to the completion of core-infrastructures such as IIA, New Songdo City, and expressways connecting Seoul and its metropolitan areas with the country's central region, Incheon, the 2nd largest port city of Korea is transforming from the gateway to enlightenment of the 19th century in Chosun Dynasty, to the base camp for international trade armed with transportation on the land, at the sea, and in the sky. Incheon Bridge, a new landmark of Asia and the core infrastructure that will lead high-technology industries of the future, will help Korea become the hub of Northeast Asia.

## 2. PROGRESS HISTORY OF THE PROJECT

- July 1999:** Suggested the construction of Incheon 2<sup>nd</sup> Bridge connecting Songdo New Town and Yeongjong Island during the visit of Ex-President D.J.Kim to Canada for economic cooperation between both nations. ※ Incheon 2<sup>nd</sup> Bridge was the former name of Incheon Bridge
- 28 Feb. 2000:** Submitted private investment project proposal for Incheon 2<sup>nd</sup> Bridge by AGRA,

Canadian company.

※ May 2000: AGRA is merged and acquired by AMEC, British company.

- 19 Mar. 2001:** Completed the deliberation for Incheon 2<sup>nd</sup> Bridge project proposal: MoCT  
※ MoCT was the former name of MLTM (Ministry of Land, Transport and Maritime Affairs)
- 14 July 2001:** Government Selected “AMEC Inc.” as “Potential Concessionaire” for this project
- 18 June 2003:** Entered into concession agreement. Designated the concessionaire of the project, KODA Development CO.Ltd. ※ KODA was the former name of Incheon Bridge Co.Ltd.
- 24 May 2004:** Selected the preferred bidder for Incheon 2<sup>nd</sup> Bridge design and construction, Samsung J/V: KODA
- 28 June 2004:** Instructed the implementation of Incheon 2<sup>nd</sup> Bridge connecting road (Government invested section) by MoCT (→KEC)
- 12 Oct. 2004:** Instructed the commencement of the advance work: MoCT
- 3 Nov. 2004:** Included Incheon 2<sup>nd</sup> Bridge into the alignment of 2<sup>nd</sup> Gyeongin Expressway (Presidential Decree No.18579)
- 17 Dec. 2004:** Determined main span length of Cabled-Stayed Bridge from 700m to 800m
- 31 Dec. 2004:** Ordering the construction work of the connecting road section .
- 22 Apr. 2005:** Implemented the bid for connecting road section.
- 3 May 2005:** Entered into Amended and Restated Concession Agreement(ARCA) (MoCT)
- 3 June 2005:** Named Incheon 2<sup>nd</sup> Bridge as Incheon Bridge.
- 16 June 2005:** Hold a ground-breaking ceremony for Incheon Bridge Project (Attendee: President of Korea)
- 1 July 2005:** Commenced the construction work of the private invested section.
- 26 Dec. 2005:** Entered into the contract for the government invested section. Commenced the construction work of the government invested section
- 23 Dec. 2007:** Launching the first large deck block on cable-stayed bridge of the private invested section.
- 16 Dec. 2008:** Closed the cable-stayed bridge of the private invested section.
- 27 Feb. 2009:** Launching the last FSLM segment of the private invested section.
- 23 Oct. 2009 :** Completion of the bridge

### **3. LINE-UP OF THE INCHEON BRIDGE**

The kernel section of Incheon Bridge is the 1.48 km (80+260+800+260+80 m) long cable-stayed bridge with two pylons. The cable-stayed bridge section has been designed to enable the passing of the 100,000 DWT vessels. Its main span measures 800 m, making it the world's 5th largest cable-stayed bridge in 2009 and the height from the sea level to the deck is more than 74 m. The reverse Y-shaped concrete pylon's height is 230.5 m, similar to that of 63 Building in Seoul. The 3-cell steel box deck is 33.4 m wide and 3 m high. Stay cables are two fan-shaped planes of new parallel wire strand cables. Aerodynamic stability of the bridge was verified by both the wind tunnel tests and numerical modeling considering cable vibrations caused by vortex, rain-wind excitation and the motion of the bridge itself.

For approach spans connecting the cable-stayed bridge, a 2.02 km long precast segmental PSC box-girder bridge by precast free cantilever method (PFCM) was constructed to the east and west directions. This approach bridge links the high level cable-stayed bridge to the low level viaducts. The alignment slope of the bridge is constant at 3 %, rising to meet the high level cable-stayed bridge. 7-span continuous concrete box girder has variable sections whose height changes from 3.0 m to 8.5 m.

At either side of this approach span, total length of 8.40 km precast PSC box-girder bridge which is 5-span continuous has been constructed as viaducts. The full span launching method (FSLM) was used for



this section. A goliath floating crane directly lifted a 50 m long precast girder of 1,350 tonf weight on the existing deck and an erection gantry system launched the girder span by span right after the transporting the girder to the installing point by a multi-axle carrier.

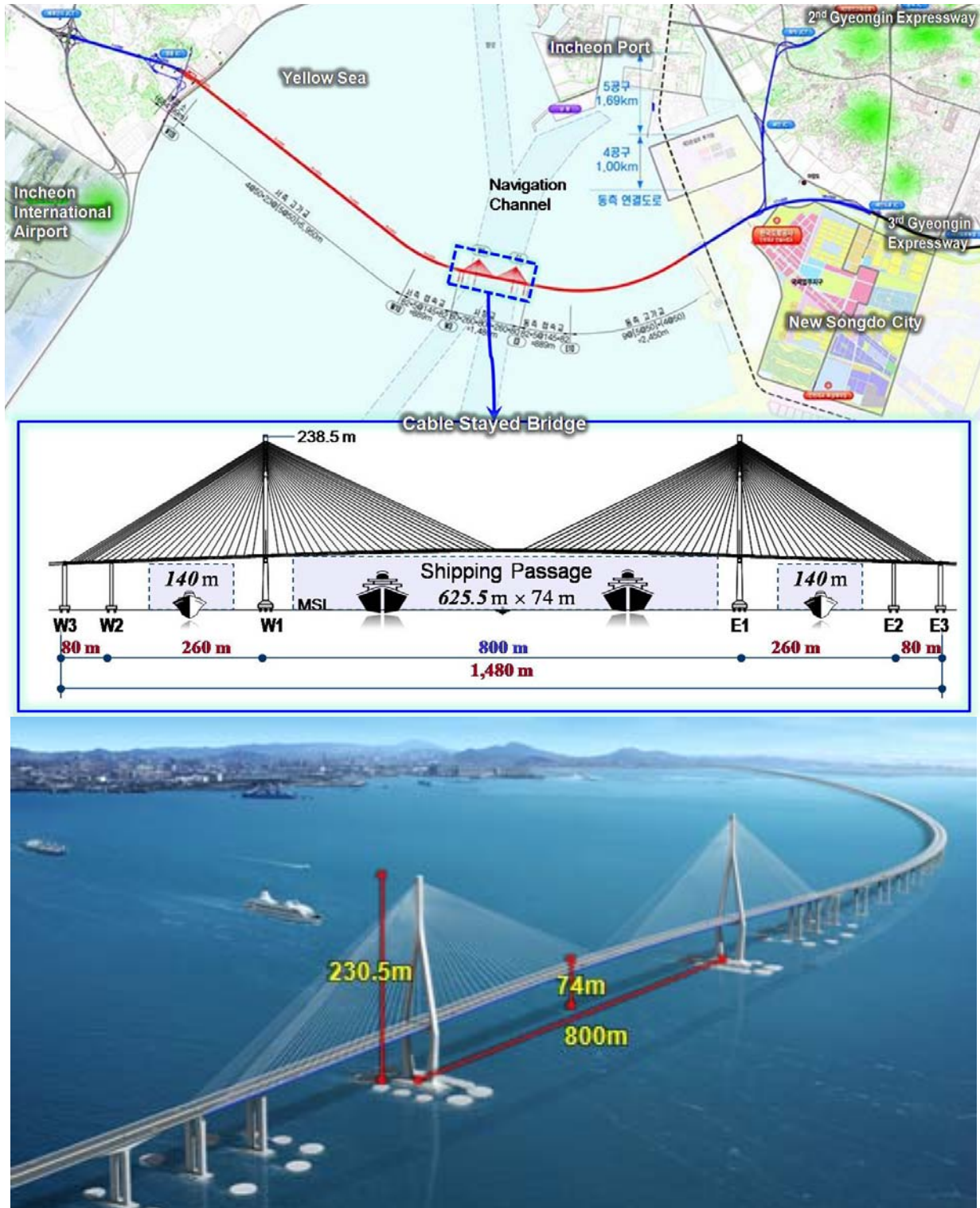


Figure 2: Route map of the Incheon Bridge and the cable stayed portion as its main section



Figure 3: Various structures of the Incheon Bridge

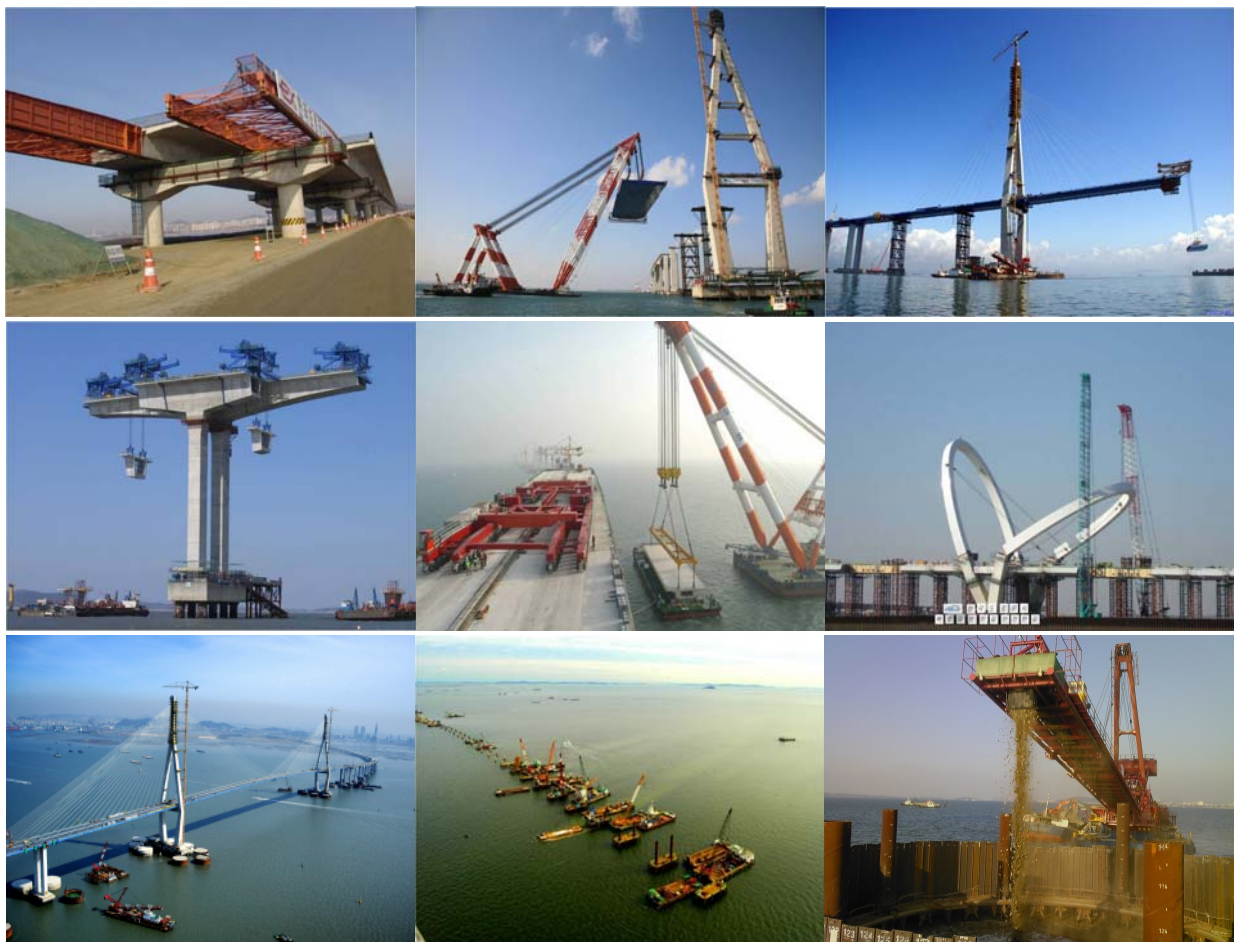


Figure 4: Construction photos



The entrance section to Songdo City area was built as a 1.25 km long PSC box-girder bridge by incremental launching method (ILM). Because it is the longest ILM bridge of Korea, there is no expansion joint in this length of 1.25 km. Then, tied arch bridge of which rib is steel tube connects the ILM bridge with Songdo Junction. To the 3rd Gyeongin expressway direction from the Songdo junction, a 2.21 km long PSC box-girder bridge with FRP strut supported decks has been completed using the movable scaffolding system (MSS). To the 2nd Gyeongin expressway direction from the Songdo junction, another cable-stayed bridge with V-shaped steel pylon crosses the lake park. And an extradosed bridge by FCM has been built across the existing coastal road. Toll plaza is near the beginning part of the bridge in Yeongjong island area.

Although superstructures of the bridge are multifarious, all the foundations consist of large diameter drilled shafts. Drilled shaft pile foundations were penetrated into the bedrock to support the colossal superstructures. The bearing capacity and deformational characteristics of the foundations were verified through the world's largest static load test using 8 full-scale pilot piles. A single pile-bent type foundation system was selected as well as the pile-cap type foundations.

Geotextile tubes, tied sheet pile walls, and trestles were utilized to overcome the very large tidal difference between ebb and flow at the foreshore site. 44 circular-cell type dolphins surround the piers near the navigation channel to protect the bridge against the collision with aberrant vessels. Each dolphin structure consists of the flat sheet piled wall and in-filled aggregates to absorb the collision impact. Rip-raps are spread around the pile to prevent the scouring of the foundation. Prefabricated vertical drains, sand compaction piles, deep cement mixings, horizontal natural-fiber drains, and other subsidiary methods were used to improve the soft ground for the site of abutments, toll plazas, and access roads.

#### **4. DESIGN OF THE BRIDGE**

New design scheme has been being implemented for the private investment section which occupies most of offshore part of the Incheon Bridge according to the project performance requirement (PPR) by the agreement between the government and the private concessionaire. PPR prescribed that the bridge design should comply with AASHTO LRFD (load & resistance factor design) specification. Incheon Bridge is the first case of the AASHTO LRFD applications to both the superstructures and the substructures in Korea.

Basic concept of the LRFD can be described as following equation.  $Q_i$  is nominal load and  $R_i$  is nominal resistance.

$$\sum r_i Q_i \leq \sum \phi R_i \quad (1)$$

Where,  $r_i$  is load factor and  $\phi$  is resistance factor.

On the other hand, Korea Bridge Design Code (KBDC) was adopted for the government financed section. Steel structures, prestressed concrete structures and geotechnical design according to the KBDC is based on the allowable stress design (ASD) concept. This duality of the design philosophy in one bridge is another trial to conquer for engineers. Some countermeasures were introduced to guarantee the reliability of the design by the LRFD concept. An independent design check on the tender design by the LRFD was carried out not only by a foreign bridge specialist engineer but also by a domestic expert consultant. They reviewed the design based on LRFD and KBDC respectively. Review results of structural part was: except for the loads and load combinations defined in AASHTO LRFD, most design results, which were obtained by reviewing the methodology stated in AASHTO LRFD and considering additional loads and load combinations stipulated in PPR, proved corresponding with KBDC. However, several discrepancies were found based on difference in design concept or due to some errors caused in the process of making Tender Design. Considering the discrepancies caused by different design concept, additional changes

will not be made to the Detailed Design within the range where given requirements are satisfied. On the contrary, the discrepancies due to flaws in Tender Design are planned to be adjusted in Detailed Design to satisfy relative requirements of AASHTO LRFD. Also review results of geotechnical part was: some discrepancies were spotted concerning bearing capacity of piles, however, those are based on the difference in design concept between KBDC and AASHTO LRFD. In the mean time, in Detailed Design, the final results of geotechnical investigation and pile load test will be reflected so as to meet the design standards of AASHTO LRFD.

Detailed design by the contractor was checked and certified by checking engineers prior to be submitted to the design supervisor (DS). DS has reviewed the checked design details and submitted it to the government after modifications. KEC, as the government position has approved the final design through the design deliberation committee. The construction supervisor (CS) selected by KEC has stated his opinions about the design to the deliberation committee.

A number of full-scale static pile load tests were conducted for both the offshore section and the onshore sections not only to determine site specific load resistance factors in the LRFD implemented sections but also to remove any excessive margin of the stability in the ASD implemented sections. 8 pilot piles were tested in order to establish criteria for bearing capacity evaluation by bi-directional loading method (Figure 3). We made a new world record static load test achieving 31,350 tonf on a single 3.0 m diameter foundation pile near the cable-stayed sites (Figure 4). The test was conducted off-shore utilizing the Osterberg Cell test. And the wind tunnel test for scaled girder section and pylon were carried out to provide some parameters for design of cable-stayed bridge. When the design of ship impact protection structure, geocentrifuge test was performed to verify the analysis program(ABAQUS) which is used to simulate the collision between ship and protection structure.

## **5. SELECTED FEATURES IN CABLE-STAYED BRIDGE SECTION**

### **5.1 Cable-stayed bridge**

One of the key feature of cable-stayed bridge is the wind resistance design since the bridge is categorized as the long-span cable-stayed bridge.

Based on PPR, a base wind velocity at an elevation of 10 m above sea level is to be 35 m/s for the completed stage and 25 m/s for the erection stages. The design wind velocity distribution is calculated from roughness factors of the terrain given in the KBDC. Based on CSR, the onset of high-speed aerodynamic instability of the full bridge should not occur for wind velocities less than 72 m/s in horizontal smooth airflow, i.e. zero angle of attack. The minimum required critical velocity for the partially erected bridge is 64 m/s with corresponding reductions for vertically inclined wind. Based on PPR and the ASCE comfort criteria<sup>1</sup>, the acceptance criteria for low speed vibrations in the completed bridge are for peak vertical accelerations of the bridge deck to be less than 5% of the gravitational acceleration. This requirement should be satisfied for wind speeds up to 20 m/s. The comfort criteria do not apply for wind speeds exceeding 20 m/s. The acceleration criteria can be converted into deflection criteria based on the frequency of vibration. For torsional vortex shedding, the criteria were based upon vertical displacement occurring at the center of the 3rd traffic lane (located 10.7m away from the deck's center).

For stay cables, according to PPR, buffeting, vortex shedding, rain-wind induced vibration, wake galloping due to pylon or neighboring cable, and other cable vibration due to vibration of pylon or girder should be considered using the rational theory. If excessive vibration occurs, proper counter measure should be set up. Based on international practices, the minimum cable damping of 0.5% is proposed. The additional damping effect from inherent damping of cable and aerodynamic damping can be considered in cable vibration

control design. For the dampers to suppress the vibration of cables, design damping value should be checked through field test result. If field test result is excessively different with design damping then additional vibration control system to satisfy the design performance level of the cable should be prepared. To secure serviceability of the bridge, the maximum displacement of the cable shall be kept under  $1/1,600$  of the cable length when the average wind velocity every 10 minutes at the pylon top is under 20m/s. The wind tunnel tests and analyses were carried out to investigate the wind-induced behaviors of the bridge during and after construction. Following categories of the tests and analyses were performed (Figure 5):

- Section Model Test I → vibration test using a 1/100 scale rigid model of deck, test for aerodynamic countermeasure, measurement of 3-component forces
- Section Model Test II → vibration test using a 1/50 scale rigid model of deck
- Free Standing Tower Model Test I → vibration test using an aeroelastic tower model, measurement of base shear forces and overturning moments
- Free Standing Tower Model Test II → measurement of 5-component forces using rigid tower model and 3-component forces using section model of tower
- Buffeting Analysis → gust response analysis of bridge under design wind load
- Flutter Analysis → measurement of flutter coefficients, checking stability against flutter
- Full Bridge Model Test → vibration test using an aeroelastic full bridge model



Figure 5: Wind tunnel test models

The stay cables in Incheon cable-stayed bridge are installed in semi-fan type with 104 units per each side. The upper most cable is 374m (side span) and 419m (main span) in straight line and in order to reduce the effect induced by wind, NPWS (new prefabricated wire system) cable wire shall be used (109~301wires, diameter 7mm, 1,770MPa). The fatigue test and tensile test were conducted to verify the cable characteristics and the results of tests are in compliance with the PTI Recommendations. The anchorage of cable is designed as steel type on the pylon side and pipe type on the box girder. In order to reduce 2nd cable stress by live load, the rubber buffer would be placed between cable and anchorage pipe. Meanwhile, the tie-down cable (NPWS, 73&151wires, diameter 7mm, 1,770MPa) is designed for intermediate and end pier in order to resist uplift reaction during action of live load. Uplift reaction by the dead load is resisted by the concrete counter weight casted inside of the girder between intermediate and end pier. And, as the stay cable vibration suppression design, the cable surface dimple processing, dampers and rubber buffer are designed (Refer to Figure 6 and 7). Guide steel pipe at each cable anchorage extends to 50cm vertically above the deck plate surface. In design stage, cable vibration is carefully studied according to PPR. Considering the durability, aesthetic aspect and performance, friction dampers were finally adopted except for several short stay cables. Friction dampers are designed to satisfy the minimum required additional damping ratio and cable amplitude criteria specified in PPR, and



have safety factor considering the several loss factor of damper and cable system. Buffers are also installed at both sides of cable anchorages. Buffer at girder side is installed near the friction damper to increase the efficiency. Especially, there is gap between girder side buffer and cable. The gap allows the friction damper to be fully functional up to specific load condition. For short stay cables, high damping rubber dampers on tower side are installed considering the efficiency and economics of the damper.

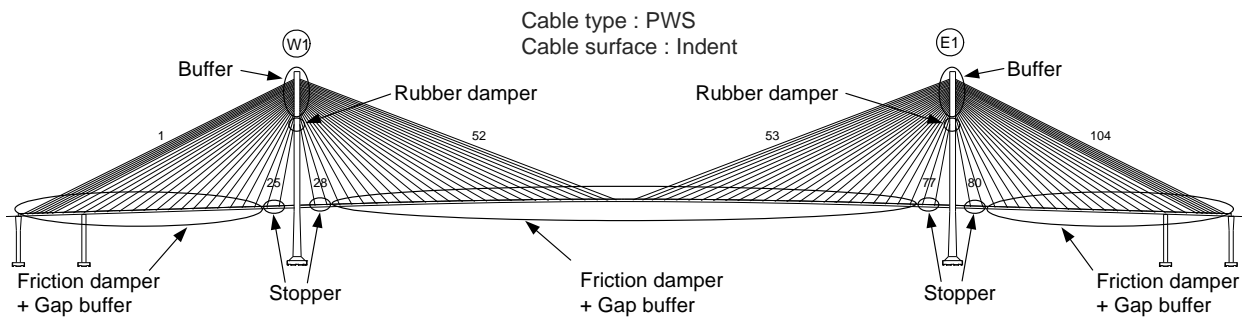


Figure 6: Arrangement of friction damper and rubber damper

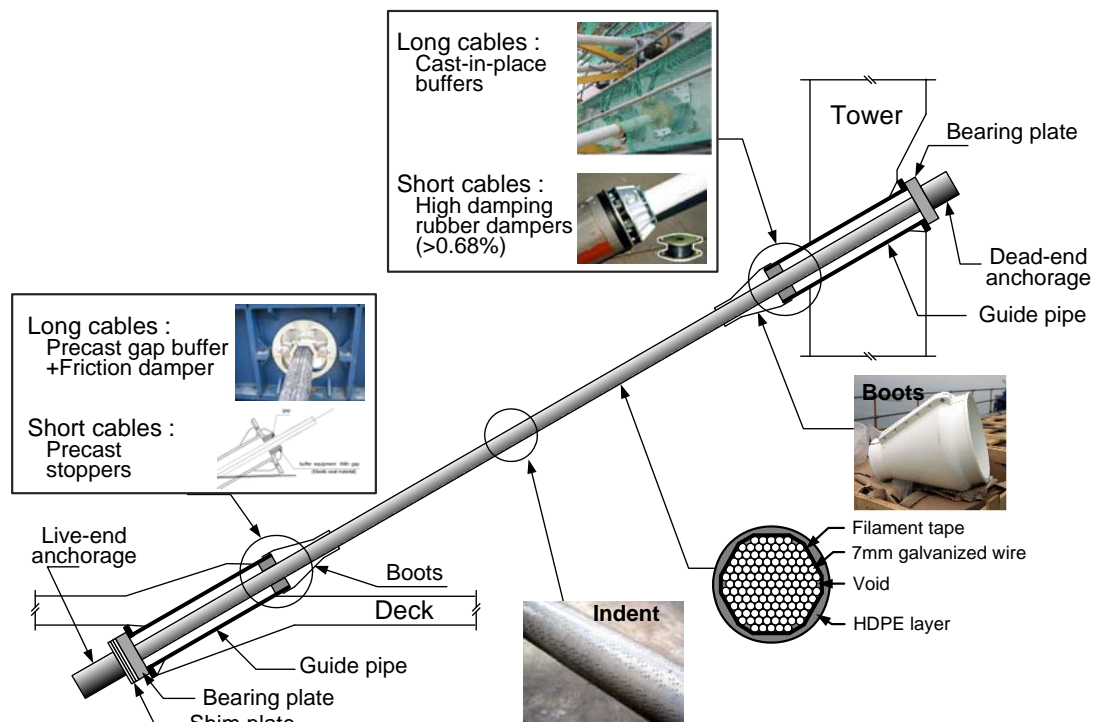


Figure 7: Arrangement of friction damper and rubber damper

## 5.2 Ship impact protection structures

The piers of Incheon cable-stayed bridge and the first near one of the approach bridge are provided with ship impact protection structures and these are in general designed in accordance with the vessel collision requirements of AASHTO LRFD Bridge Design Specifications (Figure 8). Protection structures are planned to be a circular cell of dolphin type which is composed of straight web sheet pile having 12.7 mm thickness, 50 cm in width and length of 32~40 m. Sheet pile is assembled on the casting yard and

moved to erection position on the sea by the floating crane. After driving the cell by vibro-hammer, crushed rock is immediately filled to be a stable structure. Finally cap concrete is casted on the top of the cell. Total 44 dolphins (D=25 m or 20 m) are constructed.

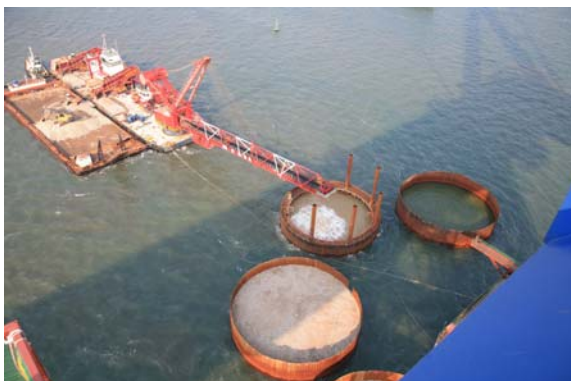
The design service life of the Incheon Bridge is in general 75 years. A shorter design service life can be accepted for secondary or replaceable structures such as the ship protection structures. Steel sheet piles of the ship protection structures is protected from corrosion through use of cathodic protection, which shall provide an expected service life of the sheet piles of not less than 60 years. Concrete structures of the ship protection structures have an expected service life of not less than 75 years.



(a) Template for sheet pile assembly



(b) Transportation of cell by floating crane



(c) Filling with crushed rocks



(d) Completed SIP structures

Figure 8: Brief procedure for construction of ship impact protection structures

## 6. CONCLUSION

Incheon Bridge will contribute to development of local construction technologies and will serve as an opportunity for the advanced project management techniques adopted in this project to be widely used in Korea. Bridge of the world, Bridge of prosperity, Bridge of safety, Bridge of cooperation and Bridge of beauty. Under this motto, Incheon Bridge will show its grand features for public in October 2009.

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